MODEL 102 VAW METER

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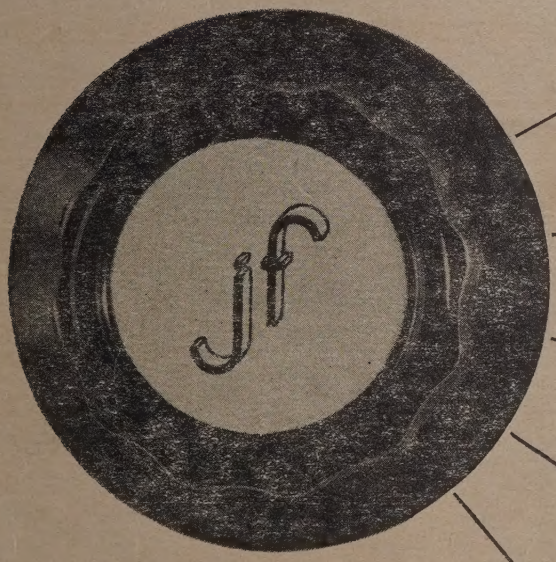
SPECIFICATIONS

OPERATION

CIRCUITS

MAINTENANCE



Electronic Tools for Industry

John Fluke Manufacturing Co., Inc.
1111 W. Nickerson St., Seattle 99, Wash.

AT-2-5700

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Issue 454

MODEL 102 VAW METER*

Electrical Specifications

Voltage Ranges: Nine: 1.5, 3, 6, 15, 30, 60, 150, 300, 600 RMS Volts

Ampere Ranges: Fourteen: .0015, .003, .006, .015, .03, .06, .15, .3, .6, 1.5, 3, 6, 15, 30 RMS Amperes.

Watt Ratings: Following table is based on unity (1) setting of POWER FACTOR SWITCH. For 0.1 setting of this switch multiply the watt values in the table below by 0.1.

Volts / Amps.	1.5	3.0	6.0	15	30	60	150	300	600
.0015	.00225	.0045	.009	.0225	.045	.09	.225	.45	.9
.003	.0045	.009	.018	.045	.09	.18	.45	.9	1.8
.006	.009	.0225	.045	.09	.225	.45	.9	1.8	3.6
.015	.0225	.045	.09	.225	.45	.9	2.25	4.5	9.0
.030	.045	.09	.18	.45	.9	1.8	4.5	9.0	18
.060	.09	.225	.45	.9	1.8	3.6	9.0	18	36
.150	.225	.450	.90	2.25	4.5	9.0	22.5	45	90
.300	.45	.9	1.8	4.5	9.0	18	45.0	90	180
.600	.9	1.8	3.6	9.0	18.0	36	90	180	360
1.5	2.25	4.5	9.0	22.5	45	90	225	450	900
3.0	4.5	9.0	18	45	90	180	450	900	1800
6.0	9.0	18	36	90	180	360	900	1800	3600
15.0	22.5	45	90	225	450	900	2250	4500	9000
30	450	900	180	450	900	1800	4500	9000	1800

Power Factor Range: Two power factor ranges are provided for the watts scales: One is for unity power factor; the other for 10% (0.1) power factor. More appropriately the 10% power factor range is a provision for expanding watt readings by a factor of ten. (see text hereof)

Frequency Range: 20 to 20,000 cycles per second.

Overall Accuracy: Within plus or minus 3% of full scale for any reading within rated frequency range.

*The VAW Meter is protected by United States Patents and the word "VAW" is a registered trade mark.

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Volt and Ampere:	In terms of the average value of the full rectified sine wave. Volt and ampere scales are calibrated in RMS values.
Watt Readings:	In terms of VACosϕ. If harmonics are present, watt readings will be the sum of powers due to fundamental and harmonics of voltage and current. There is no waveform error in watts readings for frequencies within rated values.
Meter Calibration:	Selectively reads RMS volts, RMS ampers or watts.
Scales:	All scales are linear.
Input Impedance:	Input resistance is 1 megohm for all voltage ranges. Input capacity is about 25uufd.
Shunt Drop:	Shunt drop is forty-five millivolts (0.045 mv) at full scale current.
Overload Capacity:	At least three times, appreciably more on most ranges. Limited by shunt dissipation for current and input circuits for voltage.
Regulated Power Supply:	Line voltage variations from 105 to 125 volts at 60 cps cause less than $\frac{1}{2}$% variation in readings. Highly regulated plate supply and regulated filament supply are utilized.
Power Requirements:	Nominal input voltage 117 volts, 60 cps, 135 watts. Line voltage range 105 to 125 volts.
Fuse Rating:	Three Amperes.

Mechanical Specifications

Weight:	Twenty-seven pounds.
Dimensions:	Overall size: 15$\frac{1}{2}$" wide, 10$\frac{1}{2}$" high, 13$\frac{1}{2}$" deep.
Finish:	Baked gray wrinkle enamel, smooth gray baked enamel on front panel.

OPERATING INSTRUCTIONS

GENERAL

After unpacking the Model 102, it should be carefully inspected for damage received in transit. If damage is found a claim should immediately be made against the carrier. Shunts are packed in the same container as the Model 102. Make certain that all shunts are accounted for before disposing of the shipping container. Check the contents against the packing slip.

Plug the power cord from the Model 102 into a suitable source of power rated at a nominal 117 volts, 60 cps. Turn the power switch to the "ON" position. The pilot light should glow. If not, look for a blown fuse or open pilot light. If this does not remedy the fault, disconnect the instrument immediately, and look for internal shipment damage.

Allow the instrument to warm for at least five minutes. If the instrument has been brought in from a cold atmosphere and is thoroughly chilled, allow about fifteen minutes for this warm up. Next set the "VAW" switch (lower right-hand knob) to "W", and adjust "ZERO W" knob to bring the meter pointer to zero. Plug in a shunt of desired rating; connect the circuit to be measured; set the "VOLTAGE RANGE SWITCH" to the desired range; and the instrument is ready for use. WHILE THE OPERATION OF THE MODEL 102 VAW METER IS THIS SIMPLE, PLEASE READ THE REST OF THIS INSTRUCTION BOOK FOR OPERATING DETAILS THAT WILL BE OF MUCH USE TO YOU IN GETTING THE MOST FROM THIS INSTRUMENT.

OPERATION

The following controls and fittings are provided on the Model 102 VAW METER for use in its operation.

Designation	Location	Function and Remarks
Input terminals marked "H" and "G" (Line side terminals)	Upper left front panel	"H" terminal is to be connected to high side of the POWER SOURCE. "G" terminal is grounded to Model 102 case and is to be connected to ground side of POWER SOURCE.

OPERATING INSTRUCTIONS

GENERAL

After unpacking the Model 102, it should be carefully inspected for damage received in transit. If damage is found a claim should immediately be made against the carrier. Errors are noted in the shipping container as the Model 102. Also certain small parts are packed for shipping. Check the contents against the packing slip.

Plug the power cord from the Model 102 into a suitable source of power rated at a nominal 117 volts, 60 cps. Turn the power switch to the "ON" position. The pilot light should glow. If not, look for a blown fuse or open pilot light. If this does not remedy the problem disconnect the instrument immediately, and look for internal shipping damage.

Allow the instrument to warm for at least five minutes. If the instrument has been brought in from a cold atmosphere and is thoroughly chilled, allow about fifteen minutes for this warm up. Next set the "VOM" switch (lower right-hand knob) to "M". Then adjust "ZERO ~" knob to bring the meter pointer to zero. Plug in a pair of leads; connect the circuit to be measured and the "VOLTAGE TO MEASURE" to the source and the instrument is ready for use.

OPERATION

The following controls and fittings are provided on the Model 102 VOM for use in its operation.

Designation	Location	Function and Purpose
Light bezel in terminals "M" and "G" (line side terminals)	Upper right front panel	"L" terminal is to be connected to high side of the LOAD IMPEDANCE. "M" terminal is grounded to model 102 case and is to be connected to ground side of EQUIP SOURCE.

Output terminals marked "H" and "L" (Load side terminals)	Upper left front panel	"H" terminal is to be connected to one side of LOAD. "L" terminal is to be connected to other side of LOAD. "L" is above ground by shunt drop.
Shunt jacks	Upper left front panel	Shunt plugs into these three jacks with coaxial plug at bottom.
Meter	Upper center front panel	All readings of volts (V), amperes (A) and watts (W) are read on the scales of this meter.
Zeroing knob for watts scales marked "ZERO W".	Upper right front panel	Utilized only in setting meter pointer to zero on watts scales. This "zeroing" must be done with no signal input to VAW Meter.
Voltage range switch	Lower left front panel	Utilized in setting desired, voltage range to any one of full scale values engraved on panel.
Power factor switch marked "POWER FACTOR"	Lower center front panel	Switch has two positions -".1" and "1". In position "1", full scale watts are equal to the product of shunt rating and voltage range switch setting. For ".1" position full scale watts are equal to that determined at "1" setting multiplied by 0.1 (1/10).
Reading selector switch marked "V", "A", and "W"	Lower right front panel	Causes meter to read selectively volts, amperes, or watts when this switch is respectively in "V", "A", or "W" position.
Power switch and pilot light	Lower right front panel	Power switch turns VAW Meter on in upper position, off in lower position. Pilot light shows power on.

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Fuse	Back of case	Fuse holder protrudes from rear of instrument case and is accessible without removal of any screws.
Shunt stowage	Top and back of case	Shunts may be conveniently stowed with the Model 102 by plugging them into the holes in the instrument cover.

Step-by-step Operation

1. Connect the Model 102 to a nominal 117-volt 60 cps line and allow at least a five minute warm-up period.

2. Connect lines to the VAW meter from the power source and from the load. Be sure to connect the high side of the power source to one "H" post. Connect the grounded side of the generator to the "G" post. Connect one side of the load to the other "H" post; the other side of the load to the "L" post. Connections to the "H" post may be interchanged; but connections to the "G" and "L" posts must be connected as herein described, otherwise the wattmeter will read below zero.

3. Select a shunt of suitable rating, and plug it into the shunt jacks.

4. Set the voltage selector switch to the required voltage range.

5. Set the power factor switch to position "1".

6. With no voltage or current from the power source and with the VAW switch set to "W", adjust the meter needle to zero by rotation of the "ZERO W" knob. Do not adjust this knob in the presence of any input since this may not produce a true "W Zero".

7. Cause power to flow from the generator to load. Read values of load voltage, load current, and load power, by successively rotating the "VAW" switch through "V", "A", and "W" positions.

8. If the "W" (watts) readings are less than 10% of full scale, throw the "POWER FACTOR" switch to the ".1" position. This will cause the deflection of the meter needle on watts scales to be increased by a factor of ten. Under this condition the multiplier of 0.1 must be used with indicated watts readings. Note that this feature should not be used to increase "W" readings in lieu of using a shunt which will give as near a full-scale current as possible. This will insure the best accuracy.

9. Note that with the "POWER FACTOR" switch in the "1" position, the value of the full-scale watt are is the product of the shunt rating times the setting of the voltage range switch. For example, assume that a .006 ampere shunt is plugged in and that the voltage switch is set to 6 volts. Full scale watts are then (.006)(6) or .036. The scale, amongst other markings, is marked in 36 at full scale. The scale is thus direct reading in significant figure to which must be applied a multiplying factor of .001.

10. Note that with the "POWER FACTOR" switch set in the ".1" position the value of the full scale watts is determined in 9 above but with an additional multiplier of 0.1 (1/10) applied to the watt readings. Using the above example, the full scale watts would be (.006) (6) (.1) or .0036.

Details of Operation

As in any instrument certain precautions must be observed in the operation of Model 102. First, the "G" post is connected to the case electrically. If, for some reason, the external lead connected thereto by the user is above ground, or above the potential of surrounding objects, the case likewise will be above ground or such objects. If this difference in level is sufficient to constitute a personnel hazard, adequate precautions must be taken in operating the Model 102 to prevent accidental shock. Such operation is not recommended.

The Model 102 with its ability to act as "a very low power factor wattmeter", that is, its ability to read power in highly reactive loads, represents a very high sensitivity in power measuring equipment. Consequently the "POWER FACTOR" switch should be kept in the unity or "1" position, except when actually needed in the 10% or ".1" position. If the watt reading is 10% or less of full scale, when the "POWER FACTOR" switch is in the unity (1) position, then it is permissible to throw this switch to the (.1) position. It is always, also, well to check all three readings ("V", "A", and "W") to see that they do not exceed full scale before taking any readings. This will prevent overload errors.

NOTE THE FOLLOWING PARAGRAPHS The Model 102 is not a compensated type of wattmeter owing to its multiplicity of ranges. (There are a maximum of 252 full scale values of watts ranges.) Without compensation, the wattmeter must inherently read either the power consumed in the potential circuit or the power consumed in the shunt. It is possible to omit one of those, but not both, as far as readings of watts are concerned in an uncompensated wattmeter. The choice is usually based on the minimum loss element or the one whose consequent error contribution will have to be least often taken into account.

In the Model 102 the shunt loss is read by the wattmeter. The input circuit for the Model 102 is as shown below along with the normally used external connections.

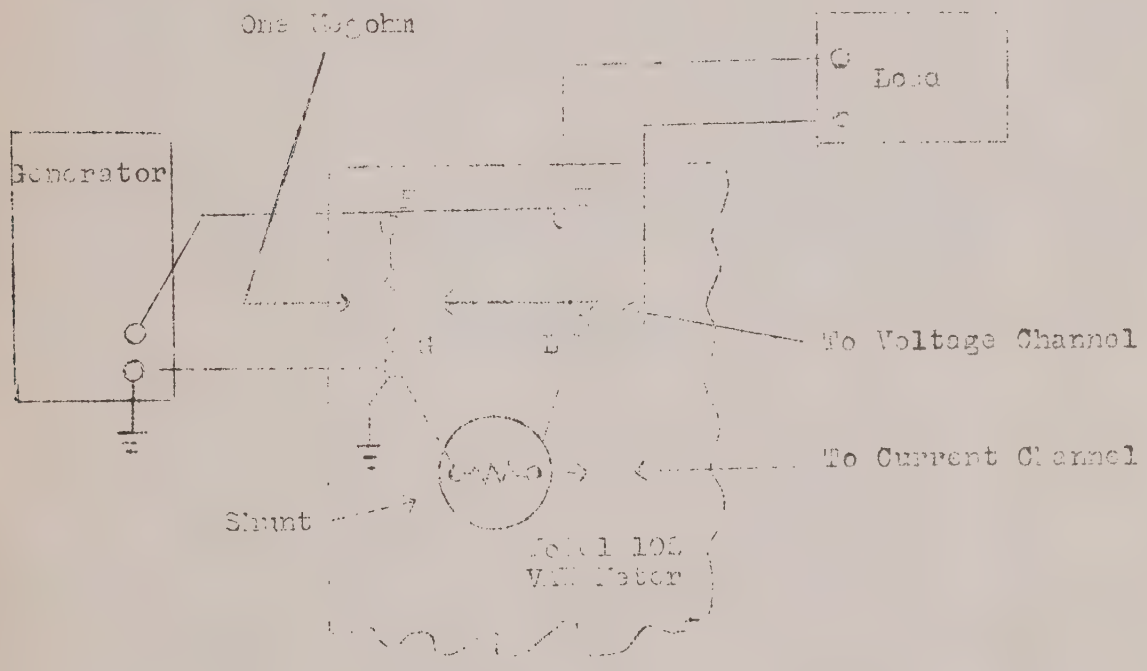

FIG. 1

Corrections for shunt loss must be made at low voltage ranges for reading low power factor watts accurately on the Model 102. This importance is greatest at the lowest voltage ranges and disappears for the upper voltage ranges. It is of little importance on the voltage readings. The shunt drop is constant for any shunt, for a given percentage of rated current since at rated current for any shunt, the shunt drop is .045 volt (45 millivolts). The resistance of any shunt may be determined by dividing .045 volt by the shunt rated current. Thus the following values are derived:

TABLE I

Shunt Rating Amperes	Shunt Resistance Ohms	Shunt Rating Amperes	Shunt Resistance Ohms
.0015	30	.3	.15
.003	15	.6	.075
.006	7.5	1.5	.03
.015	3	3.0	.015
.03	1.5	6.0	.0075
.06	.75	15.0	.003
.15	.3	30.0	.0015

Since the Model 102 reads current in amperes flowing to the load, it is obvious from FIG. 1 that this current also flows through the shunt Thus it is always possible to calculate the effects of the shunt drop. The voltage drop of the shunt is found as follows:

$$\text{Shunt drop in volts} = \frac{(\text{"A" reading})(.045)}{\text{Shunt rating}} = (\text{"A" reading})(\text{shunt res})$$

The power loss in the shunt is found as follows:

$$\text{Shunt loss in watts} = I^2R = (\text{"A" reading})^2(\text{shunt res.})$$

(all "A" values are in amperes, and shunt res. is in ohms)

Thus the voltage readings can be corrected for shunt drop by adding this drop to the voltage "V" actually read. This will be seen to be a samll error, even for the lowest scale fo 1.5 volts, since at full-scale current it can be only .045 volts or .3% of full scale. At the 3 volt range it is only .15% of full scale, at the 6 volt range .075%, etc. The watt readings are not appreciably affected by shunt loss for the unity setting of the "POWER FACTOR" switch, but they will be very appreciably affected for the .1 setting of the "POWER FACTOR" switch, for the low voltage ranges. The shunt loss watts, as computed above, should be subtracted from the value of watts read. To illustrate, let us assume that the voltage range switch is on the 1.5 volt setting, that a .006 ampere shunt is in use, and that the "POWER FACTOR" switch is in the .1 position. Also assume that full scale current, or .006 ampere, is indicated. The shunt resistance is 7.5 ohms. The shunt loss is (.006)(.006)(7.5) or .00027 watt. The full-scale watt value is (.006)(1.5)(.1) or .0009 watt. Thus the shunt loss is a very appreciable portion of the watt scale, and

it must be subtracted from the watts read on the scale. In this case the shunt loss is 30% of the full-scale value. If the "POWER FACTOR" switch had been in the unity or "1" position, the shunt loss would have been only 3% of full scale watts. Or if the voltage range switch setting had been 15 volts, the shunt loss would also have been only 3% of the full scale watts. For other voltage settings the relative values of shunt loss to full scale watts are proportional for the same current. As the current is decreased from full-scale value, whatever the shunt in use, and as the voltage range setting is increased, the shunt loss correction rapidly becomes smaller. Either a quick calculation as described herein or familiarity with the Model 102 readily will indicate whether to ignore the shunt loss or not.

Table II below has been prepared to summarize the voltage and power corrections to be applied as a function of voltage range switch setting. Note that the table is prepared for full-scale values of current and that the shunt voltage drop at full-scale current is .045 volt.

TABLE II

(1) Voltage Range Switch Setting, Volts "V"	(2) % error in voltage reading caused by shunt drop*	(3) % of full scale watt reading due to shunt loss. "Power Factor Switch" at .1**	(4) Same as (3) but for "Power Factor Switch" set at 1.0**
1.5	.3%	30%	3%
3	.15%	15%	1.5%
6	.075%	7.5%	.75%
15	.03%	3%	.3%
30	.015%	1.5%	.15%
60	.0075%	.75%	.075%
150	.003%	.3%	.03%
300	.0015%	.15%	.015%
600	.00075%	.075%	.0075%

*Error causes reading to be larger than correct value by percentage shown. For less than full-scale current error is to be multiplied by $\frac{\text{Actual Current}}{\text{Full-Scale Current}}$.

**Note that these percentages obtain for any voltage from zero plus to 100% of full scale deflection and they depend only on "Voltage Range Switch" setting and on the current being at full-scale. If the current is less than full scale, then these values are reduced by $\left(\frac{\text{Actual Current}}{\text{Full-Scale Current}}\right)$

Sometimes it may be desirable to read the power flowing to a load, one side of which is grounded. Under this condition, the generator may be found to be either grounded or ungrounded. If the latter is the case, satisfactory operation may be realized by insulating the Model 102 case from any conducting path other than the connecting leads. This will depend on the level of operation and the effect of common capacities between the load and generator and the Model 102, these capacities arising through their respective housings and through their power supply transformers, which are commonly connected to the same power system. A way of eliminating this error is by the use of the connections shows in the following sketch, FIG. 2.

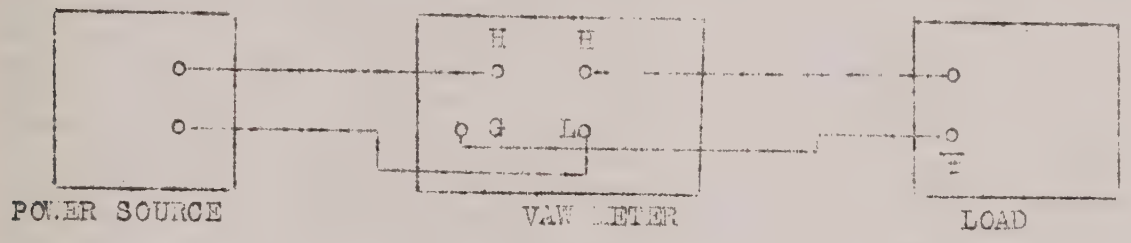

FIG. 2

If both generator and load have one side grounded, it may be desirable to use the circuit shown in FIG. 3. The transformer should have insufficient capacity between primary and secondary to short, appreciably, the shunt. The transformer has been placed on the generator side so that its losses will not be read by the wattmeter. Where the "G" and "L" posts are interchanged, it will be necessary to get into the Model 102 and reverse two connections, as noted on the circuit diagram in this manual, in order to get up-scale watt readings.

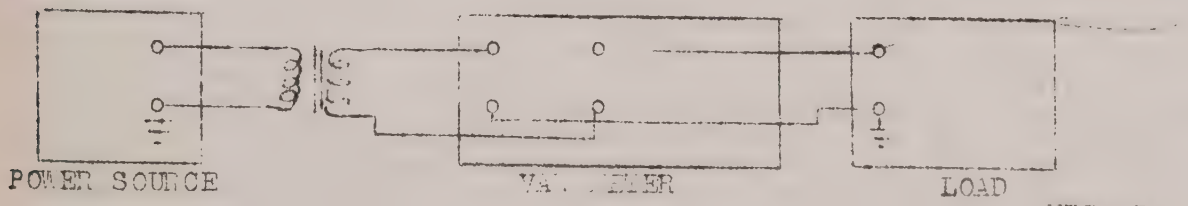

FIG. 3

There is inherently no waveform error in the watt readings presented on the VAW Meter assuming no phase or amplitude distortion in the VAW Meter amplifiers, or other residual errors such as indicating instrument non-linearities, etc. Practically the absence from waveform error is limited by the amplifiers. In the Model 102 the amplifiers have a response which is flat in amplitude and they introduce no phase shift over a frequency range in excess of 20 to 20,000 cps. Hence the Model 102 will indicate accurately the power being delivered by non-sinusoidal periodic waves of voltage and current where the fundamental frequency is 20 cps or greater and where the highest harmonics of voltage and/or current of interest do not appreciably exceed 20 KC. Hence the watt readings will be the sum of the powers due to the individual harmonic quantities. That is, the "W" readings will be $W = V_n I_n \cos\phi_n$ where "n" denotes corresponding harmonic quantities. While no practical limit can be given here for the general case, it is obvious that a wave with 20 kc fundamental, and possessing appreciable percentages of much higher harmonics, error in actual total power may derive due to failure of the Model 102 amplifiers to preserve phase relations between the various harmonics and also due to modification of the amplitudes of the harmonics. For usual cases, harmonics or frequencies as high as 40 kc will be handled with only several percent increase in error. The error is greatest for the low power factor watt ranges where very small changes in phase angle may affect the readings appreciably. You should note that at full-scale value on the 10% power factor range, the total scale arc represents only about 6 deg., or the angle between current and voltage is 84 deg. Thus the deflection of each ten percent of "W" scale, under this condition, is equal to .6 degree or 36 minutes of arc. (These angles are approx.; see trigonometric tables for more accurate values).

The volt and ampere readings are obtained by separately rectifying signals from the voltage and current channels in full-wave manner and applying the resultant signal-proportional direct voltage to the panel meter. Using full-wave rectification gives the minimum waveform error compared with half-wave or peak methods. While the error resulting from distorted waves is dependent on magnitude and phase of the harmonics, it is helpful to know the maximum value such errors may reach. Table II illustrates several cases of reading extremes for several percentages of harmonics. Note that the "V" and "A" channels of the Model 102 are calibrated in terms of RMS value of a sine wave. Note, also, from the circuit diagram, that rectifying circuit is incorporated in a feedback path. This results in high order linearity of meter readings as well as improved long term accuracy of calibration.

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The meter scale is provided with a scale marked "COSØ". This scale thus can be used to read power factor directly, or it can be used to read directly in terms of percentage of full scale when absolute values are not required. Its primary purpose is for the former use. To use this scale, set (by suitable means external to the Model 102 usually) the "V" and "A" deflections to full-scale value. Switch to "V", which will then read directly in terms of CosØ. The full-scale value of the reading will be 100%, if the "POWER FACTOR" switch is set to unity or "1"; and it will be 10%, if this switch is set to ".1". When "V" and/or "A" cannot be set to full scale conveniently, the CosØ scale reading can be multiplied by the inverse of the product of the fraction of full scale of the "V" and "A" readings. Thus if both these readings are half scale, the full scale length of CosØ is reduced to $\frac{1}{4}$ of the actual scale, and the CosØ readings must be multiplied by the inverse of $(\frac{1}{2})$ $(\frac{1}{2})$ or 4.

TABLE III

% Harmonic	Actual RMS Value	Model 102 "V" or "A" Reading	Peak Meter Reading
0	100	100	100
10% 2nd	100.5	100	90-110
20% 2nd	102	100-102	80-102
50% 2nd	112	100-110	75-150
10% 3rd	100.5	96-104	90-110
20% 3rd	102	94-108	82-120
50% 3rd	112	90-116	108-150

CIRCUIT DESCRIPTION

There are two main amplifier channels in the Model 102. One is for amplifying a voltage proportional to circuit voltage, the other is for amplifying a voltage proportional to circuit current. The output of each of these channels can be rectified and applied separately to a direct current meter whereby readings of circuit voltage or circuit current are effected. The voltage channel may have its gain adjusted by predetermined steps, by the "Voltage Range Switch", to give a total of nine different full scale values which have been selected to give the best coverage of the usual voltages encountered. The current channel effectively has its gain adjusted in predetermined steps by the fourteen standard shunts available. For reading watts, the outputs of the two amplifier channels are suitably combined and applied to a multiplier, whose output is proportional to the product of these two outputs and the cosine of their relative

	100	100
	100.0	
	102	
	110	

phase displacement in degrees. The multiplier contains no thermocouples, rectifiers, tubes, or moving parts. It is sealed in a small can and liquid filled. Normally no replacement is ever required for this unit. It should not be tampered with. Such voids any guarantee on this instrument. Should it fail, it will be replaced free of charge, when the Model 102 is returned prepaid to us, if it has not been disturbed in any manner.

The voltage channel amplifier is composed of V1 and V9 (See drawing 102-116 herewith). Switch S1 is the voltage range switch, which provides known attenuation of the voltage input. Re1 and Re2 rectify the amplified signal which is applied to the meter "M" through switch S2, the "VAW" switch.

The current channel is composed of tubes V4, V5, and V9 and performs in a manner similar to the voltage channel, with selection of appropriate connections being effected by the switch S3 being put in the "A" position.

For reading watts, Tube V2 adds the current and voltage signals. Tubes V6 and V7 subtract these two signals. These sum and difference signals are applied to two cathode followers, respectively, which apply the sum and difference signals to the multiplier. The output of the multiplier is selected by switch S2 in position "W", to apply the output of the multiplier to the panel meter and thus read watts. The power factor ranges are selected by switch S3, which modifies the gain ratio of the adding and subtracting tubes.

Filaments of several of the amplifier tubes are supplied a stabilized voltage by a ballast tube V10. This results in improved stability of readings against line voltage. This also materially improves the stability of the "W" zero against this condition.

Tubes V11 through V14 act as a stabilized power supply of very low internal impedance and high regulation. These features serve to minimize effects of changing line voltage and also help to stabilize the amplifiers to provide high fidelity amplification of signals in both amplitude and phase, which is extremely essential to this instrument.

It should be noted that in several places the circuit is equipped with "trimmer" capacitators or resistors. These are usually associated with the precision-type film resistors. You are cautioned about disturbing these components during maintenance. Their being moved may result in imparing the accuracy of watt readings in the 5 KC to 20 KC region.

P1 – I AMP GAIN (1PF)
P2 – V AMP GAIN (1PF)
P3 – W ZERO ADJ (V&F5)(A30)
P4 – W P5 ADJ (1PF)
P5 – W ZERO (FRONT PANEL)

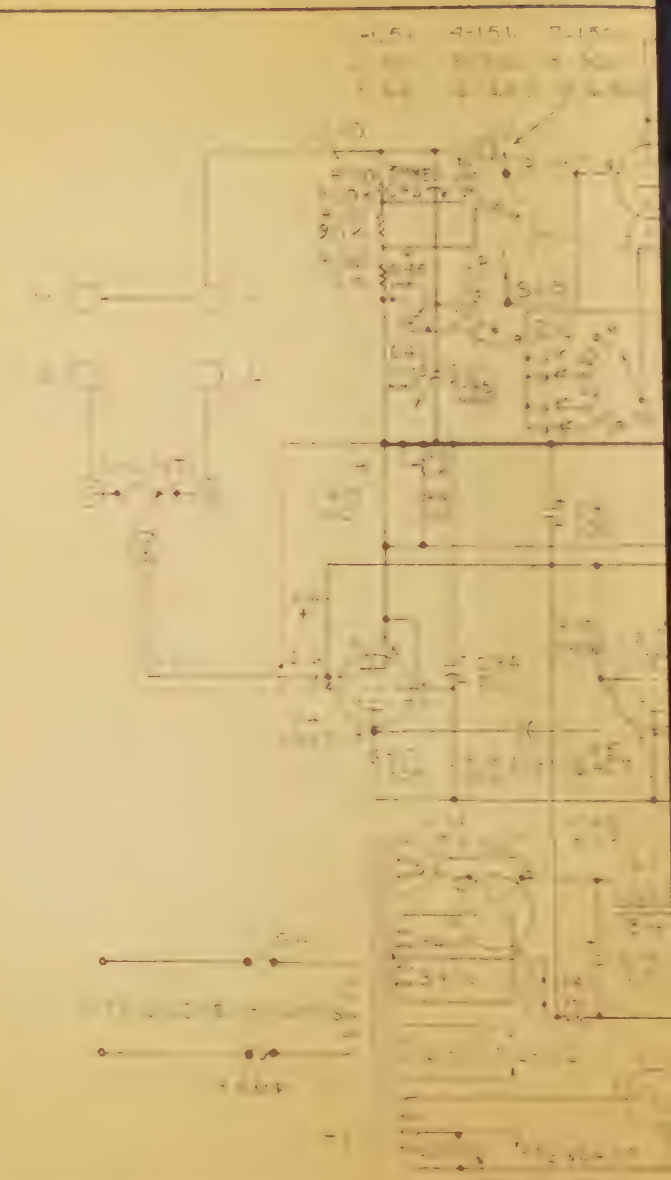
PARTS PLACEMENT
BOTTOM VIEW

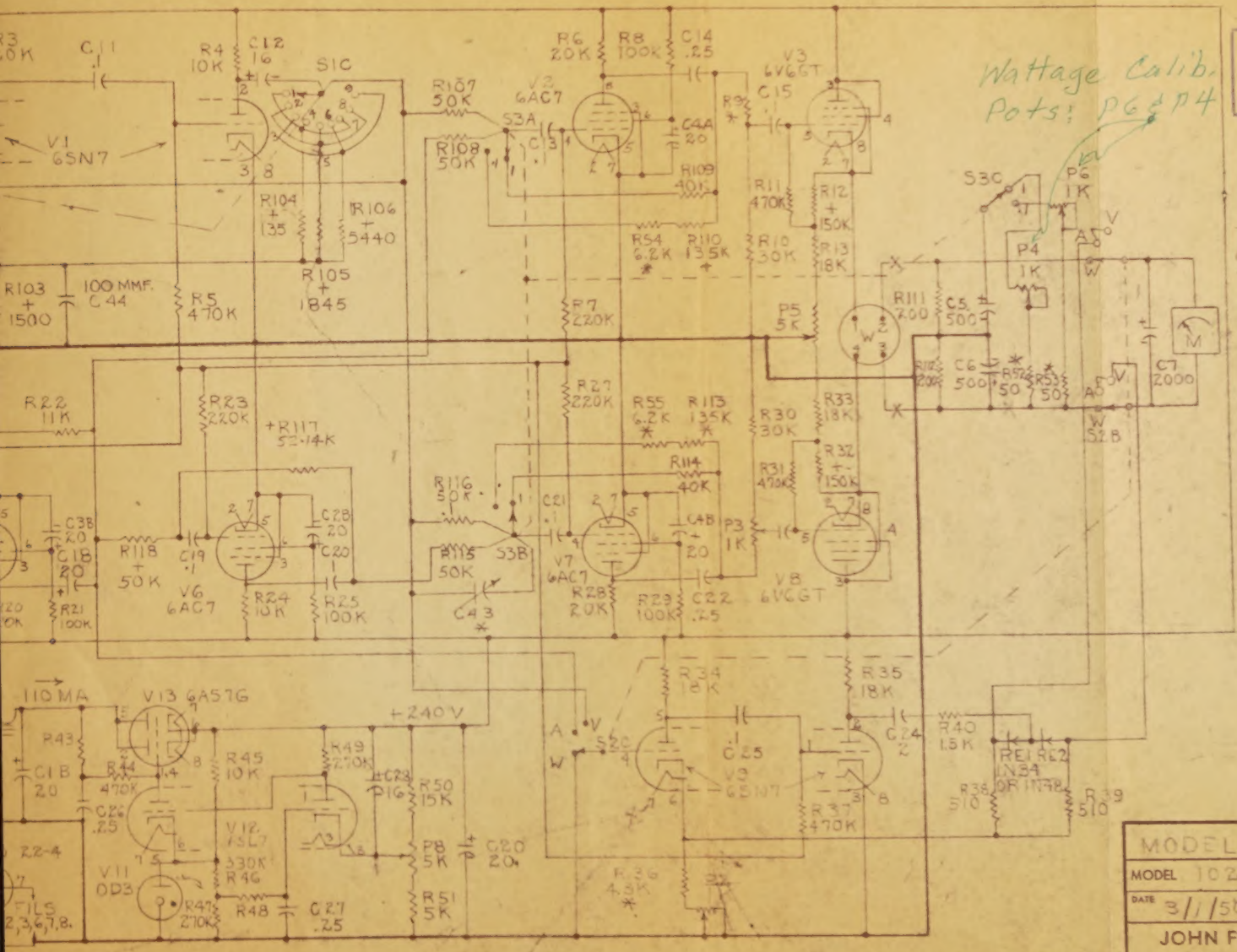
MODEL 102 | DWG. 102-120

DRAWN BY D.B | CHECKED BY

JOHN FLUKE MFG. CO., INC
SEATTLE, WASH.

NO	CHANGES	SER





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X - REVERSE THESE LEADS IF CONNECTIONS TO G&L ARE REVERSED. SEE INSTRUCTION BOOK

* COMPONENTS THUS MARKED SELECTED TO VALUE AT FACTORY. +-RESISTORS THUS MARKED MAY BE PADDED.

MODEL 108 VAW METER

MODEL 108	DWG. 02-116
DATE 3/1/50	DRAWN BY V.L.H.	CHECKED BY

JOHN FLUKE MFG. CO., INC.
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